ROBERT H. WAKE

RICHARD J. GRABLE

DETECTOR ARRAY FOR USE IN A LASER IMAGING APPARATUS

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RELATED APPLICATIONS

This application is related to provisional applications Serial Nos. 60/032,591, 60/032,592 and 60/032,593, all filed on November 29, 1996, which are hereby incorporated by reference.

10   This application is also related to copending application Serial No. 08/484,904, filed June 7, 1995, which is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to a diagnostic

15   medical imaging apparatus that employs a near-infrared laser as a radiation source and a detector array with restricted fields of views directed to their own patch of surface of the object being scanned to simultaneously detect the

intensity of light exiting from the object for use in image reconstruction.

BACKGROUND OF THE INVENTION

Cancer of the breast is a major cause of death among the American female population. Effective treatment of this disease is most readily accomplished following early detection of malignant tumors. Major efforts are presently underway to provide mass screening of the population for symptoms of breast tumors. Such screening efforts will require sophisticated, automated equipment to reliably accomplish the detection process.

The x-ray absorption density resolution of present photographic x-ray methods is insufficient to provide reliable early detection of malignant tumors. Research has indicated that the probability of metastasis increases sharply for breast tumors over 1 cm in size. Tumors of this size rarely produce sufficient contrast in a mammogram to be detectable. To produce detectable contrast in photographic mammogram 2-3 cm dimensions are required. Calcium deposits used for inferential detection of tumors in conventional mammography also appear to be associated with tumors of large size. For these reasons, photographic mammography has been relatively ineffective in the detection of this condition.

Most mammographic apparatus in use today in clinics and hospitals require breast compression techniques which are uncomfortable at best and in many cases painful to the patient. In addition, x-rays constitute ionizing radiation

which injects a further risk factor into the use of

mammographic techniques as most universally employed.

Ultrasound has also been suggested as in U.S. patent

No. 4,075,883, which requires that the breast be immersed in

5   a fluid-filled scanning chamber. U.S. Patent 3,973,126 also

requires that the breast be immersed in a fluid-filled

chamber for an x-ray scanning technique.

In recent times, the use of light and more specifically

laser light to non-invasively peer inside the body to reveal

10   the interior structure has been investigated. This

technique is called optical imaging. Optical imaging and

spectroscopy are key components of optical tomography.

Rapid progress over the past decade have brought optical

tomography to the brink of clinical usefulness. Optical

15   wavelength photons do not penetrate in vivo tissue in a

straight line as do x-ray photons. This phenomena causes

the light photons to scatter inside the tissue before the

photons emerge out of the scanned sample.

Because x-ray photons propagation is essentially

20   straight-line, relatively straight forward techniques based

on the Radon transform have been devised to produce computed

tomography images through use of computer algorithms.

Multiple measurements are made through 360° around the

scanned object. These measurements, known as projections,

25   are used to back-project the data to create an image

representative of the interior of the scanned object.

Another aspect of image reconstruction algorithm

development relates to certain assumptions concerning the

optical path through a scanned object starting at the point

30   at which the radiation beam of photons initially enters the

scanned object and the point on ~~of~~ the scanned object at which the photons finally exit. The basis for the required assumptions is that there is no direct way of visualizing the actual optical path through a scanned object, in

5 particular in vivo breast tissue, and measurements made through use of experimental models or phantoms provide empirical information of probable optical paths. _Through_ ~~Thorough~~ knowledge of the physical relationship of the radiation beam, the scanned object's perimeter, and the respective

10 sensor or sensors, reconstruction algorithm developed is possible.

In optical tomography, the process of acquiring the data that will ultimately be used for image reconstruction is the first important step. Light photon propagation is

15 not straight-line and techniques to produce cross-sectional images are mathematically intensive. To achieve adequate spatial resolution, multiple sensors are employed to measure photon flux density at small patches on the surface of the scanned object. The volume of an average female breast

20 results in the requirement that data must be acquired from a large number of patches. The photon beam attenuation induced by the breast tissue reduces the available photon flux to _an_ ~~a~~ extremely low level and requires sophisticated techniques to capture the low level signals.

25 Methods to acquire the scanning data are engineering issues that acquire low level signals, simultaneous data acquisition from a large number of sensors surrounding the breast, multiple levels of sensors surrounding the breast to allow rapid data acquisition, and both rotation and

30 translation control of sensors and laser beam.

The present invention provides efficient methods for acquisition of low level photon flux signals from multiple locations around the scanned breast.

OBJECTS AND SUMMARY OF THE INVENTION

5   It is an object of the present invention to provide a detector array for use in a laser imaging apparatus that acquires photon intensity data by direct observation of the surface of the scanned object from various observation points with known geometry.

10   It is another object of the present invention to provide a detector array configured in a circle or arc around the scanned object to allow simultaneous acquisition of photon intensity data while the detector array and the radiation beam are at one fixed location.

15   It is still another object of the present invention to provide a detector array where each of the detectors has a restricted field of view of a surface of the scanned object.

It is another object of the present invention to provide a detector array where the fields of view of two detectors are combined to view a common area on the surface of the scanned object.

In summary, the present invention provides a detector array for use in a laser imaging apparatus, comprising a plurality of housings disposed in an arc around an opening in which an object to be scanned is disposed, each housing including an open front end, a rear end and a longitudinal axis; and a detector disposed within each housing at a distance from the front end, thereby to restrict the field of view of each detector. The housings are adapted to be

orbited around the object about an orbit axis. Each detector is adapted to simultaneously detect light exiting from the object within the respective field of view of each detector. Each housing may be provided with a lens at its

5   front end to further restrict the field of view of the detector.

A method for collecting light exiting from a object being scanned with a light source is also provided, comprising the steps of providing a source of laser beam;

10   directing the laser beam toward the object being scanned; orbiting the laser beam around the object; providing a plurality of sensors adapted to simultaneously detect the laser beam after passing through the object; and restricting the field of view of each detector so that each

15   detector only sees its own patch of surface of the scanned object, each patch not overlapping with adjacent patch.

These and other objects of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTIONS OF THE DRAWINGS

20   Figure 1 is a schematic side elevational view of a scanning apparatus including a scanning chamber made in accordance with the present invention, showing a patient positioned on a support platform with her breast pendent within the scanning chamber for an optical tomographic

25   study.

Figure 2 is a schematic top view of the scanning chamber of Figure 1, showing a plurality of detector assemblies with restricted fields of views disposed around an object to be scanned.

Figure 3 is a schematic perspective view of a detector with unrestricted field of view looking at a patch of surface on the scanned object.

Figure 4 is schematic perspective view of a detector assembly with a restricted field of view looking at a smaller patch of surface on a scanned object.

Figure 5 is longitudinal cross-sectional view of a detector assembly used in the present invention.

Figure 6A is a schematic perspective view of a paraboloidal mirror with a detector disposed at its focal point.

Figure 6B is similar to Figure 6A, with the detector placed at a distance from the focal point of the mirror to restrict its field of view.

Figure 7 is a block diagram of a circuit used in the present invention to acquire data simultaneously from the detector array.

Figure 8 is a schematic perspective view of a 2-dimensional detector array, using a number of 1-dimensional arrays of Figure 2 stacked vertically.

Figure 9 is a cross-sectional view along line 9-9 of Figure 8.

Figure 10 is a schematic perspective view showing two detector assemblies with their fields of views combined to view a common area on the surface of the scanned object.

Figure 11 is a schematic perspective view of the detector assemblies of Figure 10 arranged vertically to form a two-dimensional detector array similar to Figure 8.

DETAILED DESCRIPTION OF THE INVENTION

A scanning apparatus 2, such as that described in copending application Serial No. 08/484,904, filed June 7, *now U.S. Patent No. 5,692,511,* 1995, is schematically disclosed in Figure 1. A patient 4 is positioned prone on a top surface of the apparatus 2 with her breast 6 pendent within a scanning chamber 8. A laser beam from a laser source 10 is operably associated with the scanning chamber 8 to illuminate the breast 6.

The scanning chamber 8 is shown schematically in plan view in Figure 2. The scanning chamber includes a plurality of detector assemblies 12 disposed in an arc to define an opening in which an object 14 to be scanned is positioned. A laser beam 16 impinges the object at point 18. Light exiting from the object 18, such as the rays 20 is picked up by the respective detector assembly 12, which is then used to provide an image of the scanned object. The rays 20 are represented as chords originating from the point of entry 18 of the laser beam 16 and exiting at various points on the perimeter of the scanned object. The detector assemblies 12 are digitally orbited around the object 14 about an orbit center 22 at equal angular increments for a total angular displacement of 360°. The object is illuminated with the laser beam 16 at each angular position in the orbit 23 and light emerging from the object depicted by the chords 20 at one or more locations on the perimeter of the scanned object at one instant in time or in a period of time acquired simultaneously, is picked up by the respective detector assemblies 12. Each detector assembly has its longitudinal axis directed toward the orbit center 22. The detector assemblies 12 are secured to a support 36, which is orbited

in orbit 23 around the object 14 being scanned. After each complete orbit, the array of detector assemblies 12 and the laser beam 16 are moved vertically to a new position to scan a different slice plane of the object. This is repeated until all the slice planes of the object has been scanned.

Each detector assembly 12 includes an opaque housing 24 with an open front end 26 and a rear end 28 in which a detector 30 is disposed. The housing 24 can be tubular, round, square or other cross-sectional shape. The housing 24 is designed to restrict the field of view of its respective detector 30, such that each detector is only looking at its own smaller area of the scanned object. The field of view of each detector assembly 12 is schematically indicated at 32. A patch or surface seen on the scanned object by the respective detector assembly is schematically indicated at 34.

The field of view 32 and the respective patch of surface 34 are configured such that adjacent patches of surface do not overlap each other. In this way, each detector assembly is uniquely assigned to a patch of surface at each angular position of the orbit so that light coming from one patch of surface could only be detected by the respective detector whose field of view covers that particular patch of surface. Each detector 30 is active to detect any light emerging from its respective patch of surface, since the light beam 16 can course through the object in any paths, such as those depicted by the chords 20.

The laser beam 16 may be provided by a near infrared laser, a laser diode or other near infrared sources. The

detectors 30 may be photo-diodes, avalanche photo-diodes photo-transistors, PIN diodes, photo-multiplier tubes or other photo-sensitive devices.

5   The detector 30 without using the housing 24 would have an unrestricted view 40 on a portion of the surface 42 that can be seen on a slice plane 44 from the object being scanned, as best shown in Figure 3. When the field of view of the detector 30 is restricted, through the use of housing 24, the surface on the slice plane 44 that can be seen by

10   the detector is reduced to a smaller patch of surface 34, as best shown in Figure 4. By restricting the field of view of each detector the surface viewed by each detector will not overlap with the other viewed surfaces, thereby providing accuracy to the data provided by each detector.

15   The open front end 26 of each housing 24 may be provided with a lens 46 to further restrict the field of view of the detector 30, as best shown in Figure 5. The focal length F of the lens 46 and the diameter D1 of the detector 30 combine to restrict the field of view as

20   described by the following equation,

$$\text{ß} = \tfrac{1}{2} \text{ field of view}$$

$$= (D1)^2 / (2 * F) \text{ radians} \qquad (1)$$

Parallel ray 48 converges to indicate the position of the focal point on the detector 30. The non-parallel ray 52

25   at or less than the acceptance angle ß will passes through the lens 46 and is directed to the detector 30. Rays having an angle greater than the acceptance angle ß will not reach the detector 30.

The numerical aperture controls the angle of light

30   accepted by the lens 46. As the F-number of the lens

.increases, the acceptance angle decreases and the field of view becomes narrower. The F-number of the lens is defined as,

$$F\text{-number} = F/D1. \tag{2}$$

5   The numerical aperture of a lens is defined as,

$$\text{Numerical Aperture} = 0.5/F\text{-number}. \tag{3}$$

When the focal length F of the lens 46 increases, the acceptance angle ß decreases. Any non-parallel rays outside the acceptance angle ß will miss the detector 30. A lower

10   acceptance angle ß further restricts the field of view of the detector 30. Other lens combinations may be made to restrict the field of view of the detector 30.

Another way of restricting the field of view of the detector 30 is disclosed in Figures 6A and 6B. A

15   paraboloidal mirror 54 with a field of view 56. Parallel rays 58 converge on the focus point 60. The detector 30 placed at the focus point 60 will receive the parallel rays 58 within the field of view 56. To restrict the field of view of the mirror 54 to a smaller area 62, the detector 30

20   is displaced at distance d away from the focus point 60, as best shown in Figure 6B. Rays 66 that are outside of the field of view 62 are seen to miss the detector 30. Other mirror combinations are possible that would result in similar field of view restriction.

25   Knowledge of the restricted field of view 32 of the detectors 30, the physical position of the detectors assemblies in the array relative to the axis of the orbit of rotation, the paths of the photons within the scanned object as represented by the chords 20 and knowledge of the photons

30   emerging from the scanned object at one or more locations on

the perimeter of the scanned object at one instant in time or in a period of time acquired simultaneously, provide information for image reconstruction.

A circuit for acquiring data for one or more of the
5   detectors 30 is disclosed in Figure 7. Each detector 30 is coupled to a sample and hold integrator 68. During the sample interval, a signal is developed by the integrator 68 as a function of the photons striking the detector 30. During the hold interval, the detector input is terminated
10   and the integrated signal level is held at the level it reached during the sample interval. A multiplexer 70 is used to connect the respective integrator outputs to an analog to digital converter 72. The digitized individual detector or sensor response is stored in memory 74 for later
15   use in image reconstruction. The circuit allows for simultaneous acquisition of data from all the detectors 30. The circuit in image reconstruction are described in provisional applications Serial Nos. 60/032,590 and 60/032,594 both filed on November 29, 1996, which are hereby
20   incorporated by reference. Determination of the boundary perimeter of the scanned object is disclosed in provisional applications Serial Nos. 60/029,897 and 60/029,898, both filed November 8, 1996, which are hereby incorporated by reference.

25   The detector assemblies 12 may be arranged in a 2-dimensional array, where the detector assemblies are arrayed horizontally and vertically, as best shown in Figures 8 and 9. The object being scanned is divided into contiguous slice planes 44. The 2-dimensional array is
30   configured to simultaneously acquire data from the

contiguous slice planes 76 within the scanned object. The simultaneous acquisition of data significantly reduces the time required to scan the entire object. The acquired data is then used to reconstruct either single slice planes or

5   3-dimensional reconstruction of the scanned object, taking advantage of ray paths that cross slice planes.

Two detector assemblies 12 may be combined to share a common field of view on the patch of surface of the scanned object. The use of two detectors 30 significantly increases

10   the number of photons that can be seen radiating from the respective patch of surface of the scanned object, as best shown in Figure 10. The doubled-up detectors assemblies, in addition to being arrayed horizontally, may also be arranged vertically to form a 2-dimensional configuration to create a

15   "wall" of detectors, as best shown in Figure 11. The arrangement is used to simultaneously acquire data from contiguously slice planes within a scanned object. The acquired data can be used to reconstruct either a single slice image or a 3-dimensional reconstruction of the scanned

20   object.

While this invention has been described as having preferred design, it is understood that it is capable of further modification, uses and/or adaptations following in general the principle of the invention and including such

25   departures from the present disclosure as come within known or customary practice in the art to which the invention pertains, and as may be applied to the essential features set forth, and fall within the scope of the invention or the limits of the appended claims.